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Artificial Neural Network based grid integrated wind MPPT system

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ABSTRACT

Increasing demand of PMSG based wind system as a renewable energy resource needs to track its maximum power using effective algorithms. As wind system has uncertainity in the wind speed, accordingly its MPP also varies. Although various algorithms have been propose, still there is a need of developing effective MPPT algorithm that can track the global maxima. Presently an ANN based MPP algorithm is proposed and compared with P & O algorithm. Also further the model is validated under varying wind speed and connected to grid. The results strongly suggest the proposed ANN approach over P & O method.

Keywords: Wind system, MPPT, P&O, ANN, Grid.

1.INTRODUCTION

The role of energy is critical for the globe, which is typically reliant on resources such as nuclear, fossil, and so on. However, they raise the danger of environmental damage, which has attracted attention to the need for an alternative, nontraditional source of energy. Wind and solar power systems (PV) are the most common renewable energy sources because they are clean, safe, and can be deployed with no fuel costs, little maintenance, and no noise or pollution.

The MPPT controller technique is completely responsible for the wind system's efficiency. However, common techniques such as Pertub and Observe (P&O) and incremental conductance (I&C) fail to achieve the global minima point under various wind conditions. Although the PO method is a simpler solution for MPPT, it typically generates oscillations around the global minima point, which fails under quickly changing environmental (temperature and irradiance) circumstances[1]. However, the I&C algorithm performs better in such environmental settings despite being considerably more critical in nature [1-2]. Other solutions, such as the constant voltage or / and constant current approaches, are likewise simple to construct, but they do not correctly track the maximum point [1-2]. The beta-approach, on the other hand, has a decent capacity to handle MPP situations but is computationally cricital and requires a suitable selection of beta-factor [2]. For partially shedded situations, the entire method fails. As a result, several techniques have been devised, which are further debated and scattered throughout the literature. Although certain MPPT strategies are appropriate for smallscale wind systems, they fail in big systems owing to partial shedding. As a result, all of the aforementioned MPPT techniques are unsuitable for achieving the global MPP under fluctuating wind conditions. Under such conditions, numerous ways [11,16] are the global tracking method, however they are not very acceptable in terms of efficiency and have a higher computational cost. The current literature employs a well-known heuristic technique known as the Artificial Neural Network (ANN) algorithm. The ANN-based maximum power point (MPP) tracker integrates environmental data and estimates the current and voltage corresponding to the solar panel's maximum power. PO and ANN implementation and performance are described and compared.

2. WIND SYSTEM

Wind is caused by the sun's uneven heating of the Earth's surface. Wind turbines harness the kinetic energy of the wind and transform it into clean power. When the wind rotates the blades of a wind turbine, a rotor catches the kinetic energy of the wind and turns it into rotational motion to power the generator. To protect the rotor from spinning out of control in strong winds, most turbines feature automated overspeed-governing mechanisms. More information on how wind systems work and the benefits they give may be found in our wind power animation. A modest wind system can be connected to the electric grid via your power provider or it can operate independently(off-grid). As a result, modest wind electric systems are an excellent solution for rural regions that are not yet linked to the electric grid.

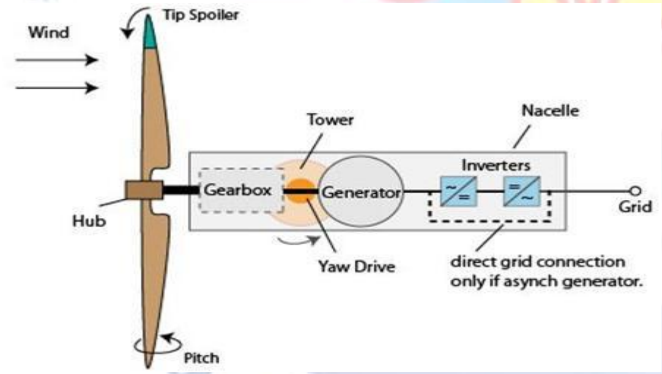

Fig. 1. Wind model

A. *Mathematical modeling*

The power generated by a wind turbine can be represented as in [1]

$$\mathbf{Pm = 0.5\pi\varrho Cp(\lambda, \beta)R^2v^3\omega} \quad (1)$$

where R is the radius of the turbine, vw is the wind speed, rho is the density of the air, Cp is the power coefficient, lambda is the tip speed ratio, and beta is the pitch angle beta is set to zero in this work. The tip speed ratio can be presented as in the following equation:

$$\lambda = \frac{\omega_r R}{V\omega} (2)$$

where ω_r is the angular speed of the turbine The wind turbine's dynamic equation is as follows:

$$\frac{d\omega_r}{dt} = \frac{1}{J}[\mathrm{Tm} - \mathrm{T}L - \mathrm{T}\omega_r] \quad (3)$$

Where is the system inertia, F is the viscous friction coefficient, Tm is the turbine torque, and TL is the torque owing to load, which is the generator torque in this example. A wind turbine's target optimal power may be expressed as

$$P_{max} = K_{opt} w_{r\_opt}^3 \quad (4)$$

where,

$$K_{opt} = \frac{0.5\pi\rho C_{p\_max} R^5}{\lambda_{opt}^3} \quad (5)$$

$$w_{opt} = \frac{\lambda_{opt} v_w}{R} \quad (6)$$

At various wind speeds, Fig 2 displays turbine mechanical power as a function of rotor speed. The power output for a given wind speed is maximised at a specific rotor speed, known as the optimal rotor speed Wopt. This is the speed that corresponds to the lambda_opt ideal tip speed ratio. The turbine should always run at lambda_opt in order to get the most power out of it. This is accomplished by regulating the turbine's rotational speed such that it always rotates at the optimal pace.

3. DC-DC CONVERTER FOR WIND SYSTEM

The configuration of the buck converter is presented in Fig.3. From the figure it can be seen that, there four main components exists such as: 1) switching power MOSFET Q1, 2) flywheel diode D1, 3) inductor L and 4) output filter capacitor C1. Often a control circuit with a single chip controls the power level by varying the voltage and current, and controls the performance with a desired level of operation with the help of switching element Q1 on and off at a fixed rate which is generally called as the converter's operating frequency. While, with a variation in the PWM ratio the performances are adjusted accordingly. The current flows from the input source through Q1 and when Q1 is turned on, then further it

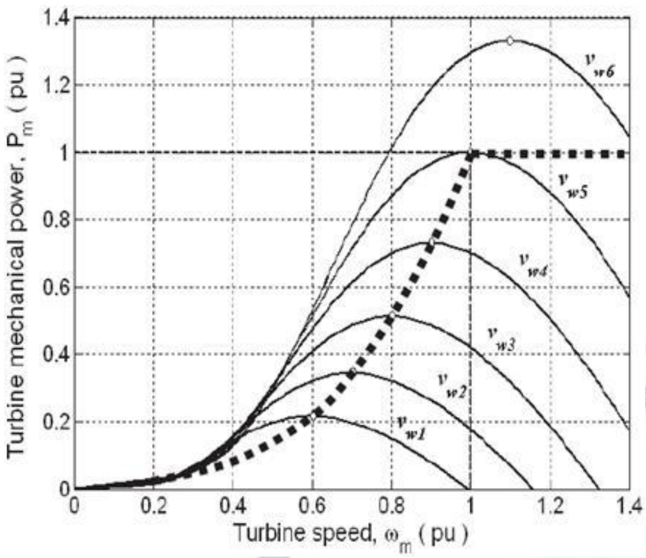

Fig. 2. Turbine mechanical power as a function of rotor speed for various wind speeds

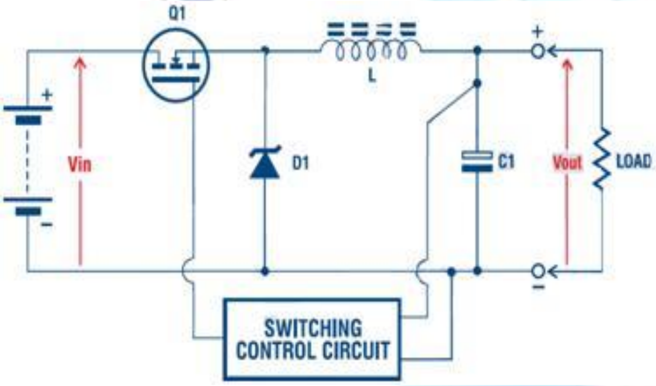

Fig. 3. The basic circuit for a Buck type of DC-DC converter

flows into C1 to reach up to the load. When the Q1 is off and the source voltage is present the inductor L energiges and stores the current in the form of magnetic field. After some time when the inductor is fully charged, it changes it state from an insulator to conductor and the full current is flown from the source towards the diode D1. If discharged, the capacitor C1 gets charged and stores the energy in terms of electrical form. However when the capacitor C1 is also charged fully it does not pass the current through it making a potential difference of same as input source. So the the current is directly frloen to the load reasulting a high voltage to appear as in input source. However, when the switch Q1 is turned on an extra current is flown from the Q1 terminals and the load current increases.

4. MAXIMUM POWER POINT TRACKING

The general features of the speed-power curve reflect a specific location where the highest power is measured for wind models. The resultant power has a voltage and current rating that must be met. An MPPT algorithm, on the other hand, must first discover the ideal voltage and current combination.

Fig. 4. Wind model with DC-DC converter

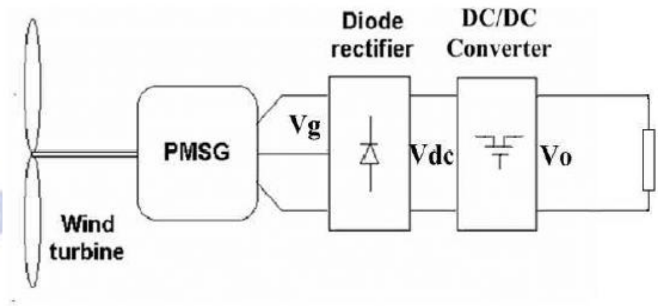

Fig. 4. Wind model with DC-DC converter

Even while the idea of wind applies to sources of changing power, there is variance owing to various features of these elements. The reference with their relationship of inverter systems, battery banks, external grids, and/or industrial/domestic electrical loads [5], due to the variably constructed wind systems. Taking all of these factors into account, the algorithm should be able to track the ideal voltage and current combination.

A. *Pertub and Observe algorithm*

This is essentially a search procedure in which the voltage is altered and the voltage changes a certain level at each stage to acquire the optimal power. [13] [14] This is known as the hill ascending process because it is based on the gradient of the power level, which resembles a hill. [15]. For its simplicity, the Pertub and Observe algorithm P&O is the most often used MPPT technique. [13] The global optimum can only be reached via the P&O approach if a correct strategy is used[16] [17].

B. *Proposed ANN based MPPT*

A human brain replication, with the help of mathematical models, leading to the computational strategy for information processing, is widely known as Artificial Neural Network (ANN). ANN consists of multiple layers with interconnected neurons (refer Fig. 6), where, each neuron can be represented as in Fig. 7. The input layer is generally characterized by the independent variables and output layer by dependent variables. Specifically for regression, the configuration of ANN can be;

1) Multiple Input - Single Output or 2) Multiple Input - Multiple Output systems. Based on the trained data, the ANN can learn the relationship between input and output hyper dimensional spaces. And thus the trained model can further be tested on the real-time data for validating the learning performance. ANN learning

process generally employed with the back propagation approach, which, update the weight and bias of the neurons to minimize the error or loss function.

Different architecture of ANN are explored and validated for various applications such as; classification, regression, pattern recognition and so on. For organizations, instead of storing all in-hand data (in exponential scale), the informative and redundant data can be extracted; which can be an efficient

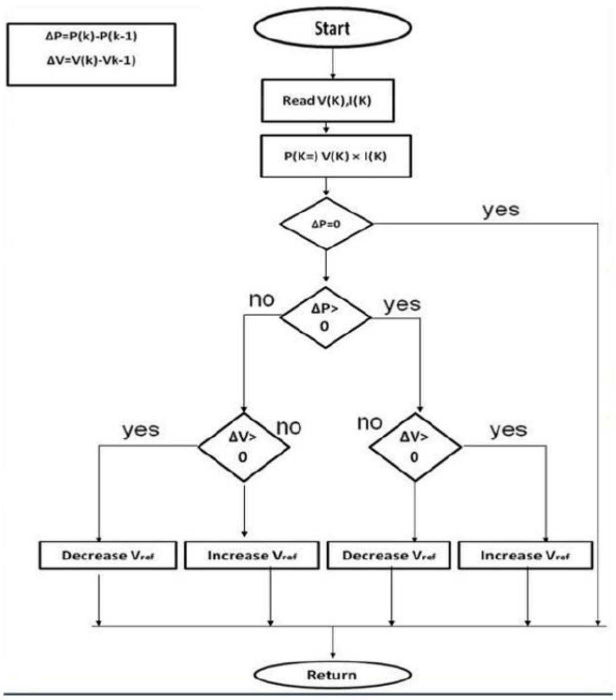

Fig. 5. Pertub and Observe algorithm

way to predict the desire outcome. Recently, this exploration is proved fruitful by many researchers, leading to the application of ANN for numerous prediction tasks. In the past decade, several such predictions are proposed for stock prediction, electricity forecasting, labor productivity etc.

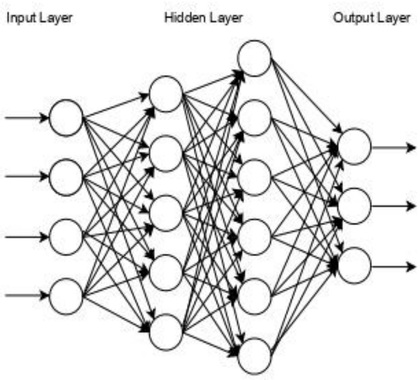

Fig. 6. General architecture of Artificial Neural Network

The general architecture of ANN is shown in Fig 6 comprising of multiple layers. The input layer have neurons, exactly same amount of independent variables (feature space) in the dataset, while, each neuron in the output layer refers to the prediction outcomes. Whereas, there may be multiple hidden layers and the size generally depends on the information in the input data, and are decided empirically with multiple trials. Also, each hidden layer can consist of multiple neurons and the exact solution to the volume is still hindered among researchers.

Fig. 7. Building block of Artificial Neural Network

The ANN can be described as a functional representation from the input (observation) space X to output (decision) space Y (Eq. 7).

$$f : X \to Y \tag{7}$$

For input feature space X with n features as (x_1, x_2,..xn), the linear relationship to output Y ′ of the neuron can be described as in Eq. 8.

$$Y' = \sum_{i=1}^{n} x_i w_i + b \tag{8}$$

where, b represents a bias term which is added to the sum of multiplicative weights $W \ (w_1, w_2, .., w_n)$ with the input feature space. In most of the real-time applications, the highly non-linear systems can be modeled with the help of ANN by introducing the transfer function. Such transfer function is characterized by the activation function as shown in Fig. 7 and Eq. 9.

$$Y = \varphi(Y') = \varphi\left(\sum_{i=1}^{n} x_i w_i + b\right) \tag{9}$$

where, activation function ϕ(.) generally are nonlinear functions [?] such as ; logsig(), tansig(), purelin() etc. The transfer functions are empirically selected based on trial and error strategy to best fit the specific regression or classification task. The ANN is generally trained using back propagation approach. The training is performed to reduce the error performance of the network by updating the weight and bias associated with each neuron. Commonly, the random initialized weight and bias are updated with the help of stochastic gradient descend algorithm to minimize the learning error. Proposed ANN based MPPT for grid integrated wind system is shown in Fig 8.

5.GRID INTEGRATION

A power electronic device system is needed for operation of variable speed WT for synchronizing voltage of the electrical grid with the generator frequency. PMSG WECS includes PMSG wind turbine is connected with full scale power converter along with connection to the electrical power grid. The power generated power from wind turbine can be controlled with good grid backup feature and speed control technique. Below figure shows the block diagram of PMSGbased WECS.

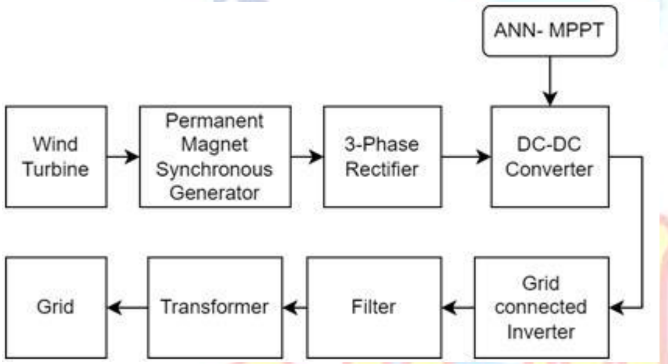

Fig. 8. Block diagram of proposed ANN based MPPT for grid integrated wind system

In this type of wind energy conversion system a PMSG machine is coupled with the wind turbine and stator terminals of the PMSG is connected to the electrical grid through a two-step power conversion system (AC-DC-AC), grid coupling filter and step-up transformer.

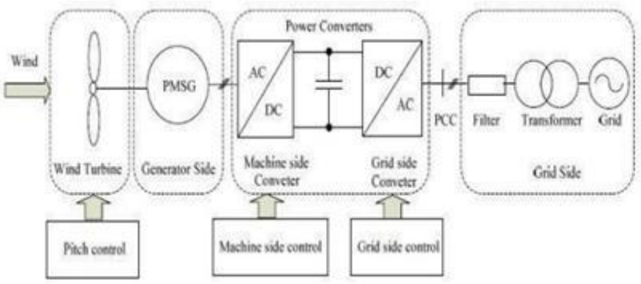

Fig. 9. Detailed model of grid integrated PMSG

Although wind energy is the one of the fastest growing industry in the world but the fact cannot be denied that its output is totally dependent on wind speed any kind of fluctuations in the wind speed affects the output of the wind turbine. Therefore integration of wind turbine with the grid is challenging task, as a result several maintenance and operation issues as well as design issues have to be taken care of. In order to tackle such problems the grid operators issues some specific grid codes and to maintain the stability of the grid the wind power plants have to abide by the codes, hence it assures that the power production by the renewable energy power plants and conventional power plants whose performance differ in nature are merged easily in the grid. In order to make sure that electricity is safely distributed to the end users safely through grid, different countries specify their own technical requirements for the grid codes and the energy production and distribution parties in the open market has to follow the technical requirements set by the respective countries.

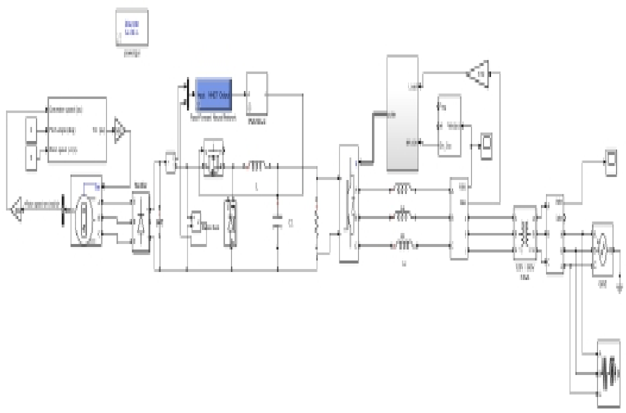

Fig. 10. Detailed model of grid integrated PMSG with proposed ANN MPPT approach

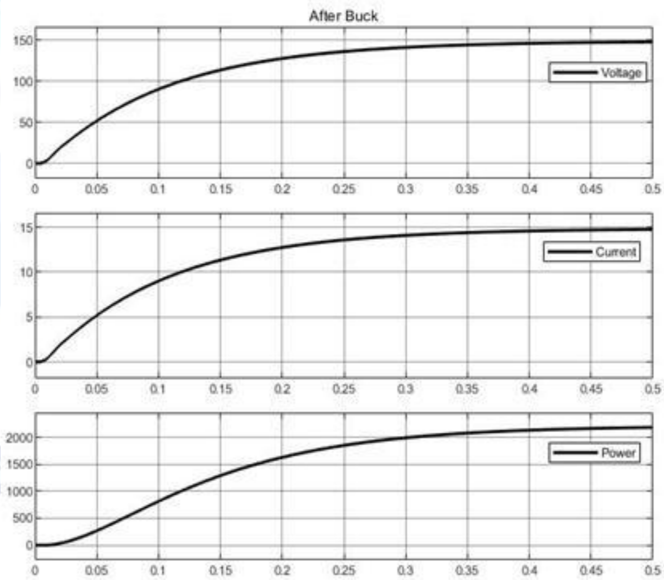

Fig. 11. Voltage and current waveform of wind DC-DC converter using P and O MPPT approach

6. SIMULATION RESULTS & CONCLUSION

Presently, the analysis, design of wind system is carried out to find their respective power characteristics with varying wind conditions. The relevance of optimization algorithms is revealed by the findings of the charactertics, which cannot be solved by other state-of-the-art methodologies such as P&O. The same can be concluded based on the acquired results (figures). The wind model characteristics cannot be pre-assumed due to the variable nature of the wind speed. As a result, nonlinear ANN techniques may be the best-fit solution to the situation at hand. A similar implementation is carried out, with positive outcomes. Also further wind system is integrated with grid system and their output wave forms are analyzed. However, further analysis on different heuristic approaches and application can also aimed as a future extension to the project.

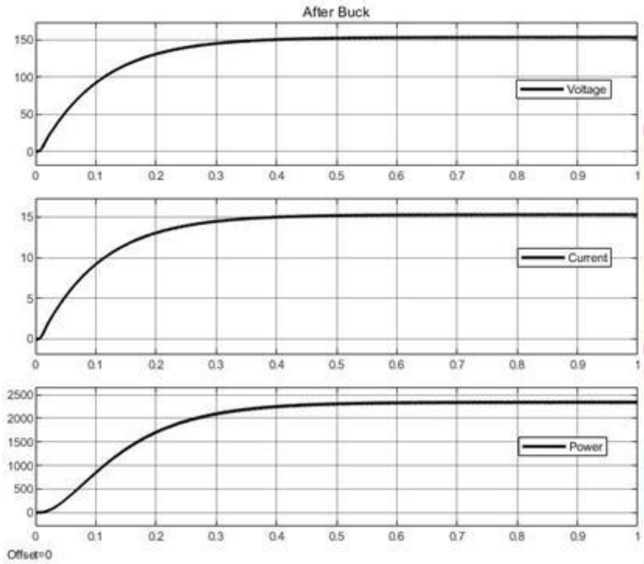

Fig. 12. Voltage and current waveform of wind DC-DC converter using proposed ANN MPPT approach

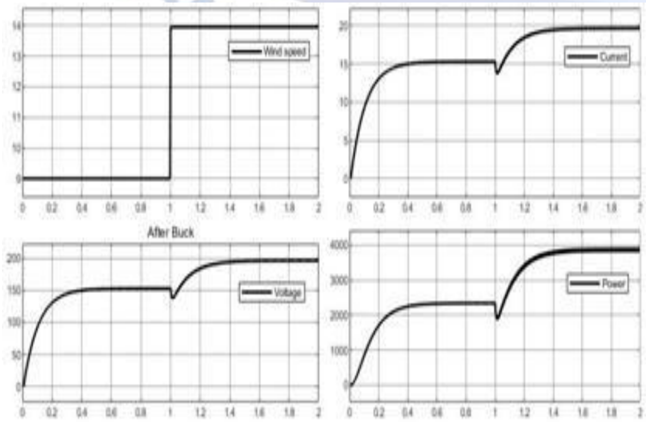

Fig. 13.Voltage, current and power waveform of wind DC-DC converter using proposed ANN MPPT approach

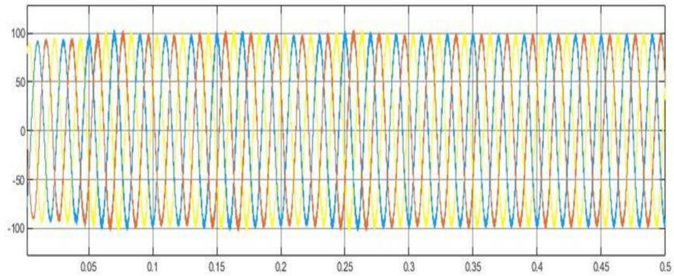

Fig. 14. Inverter output Voltage

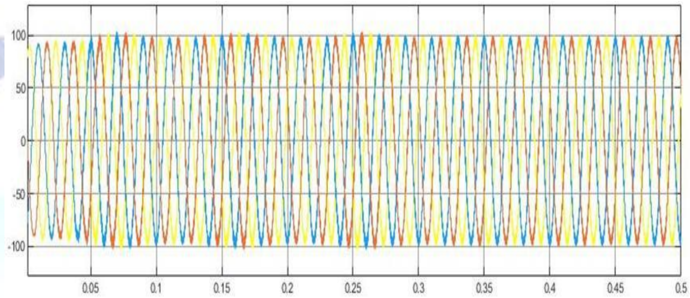

Fig. 15. Grid Voltage after integration

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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